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Alternative Bio-Derived JP-8 Class Fuel and JP-8 Fuel: Flame Tube Combustor Test Results Compared using a GE TAPS Injector Configuration

Yolanda R. Hicks

Robert Anderson, Sarah Tedder

Glenn Research Center

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Motivation and Objectives

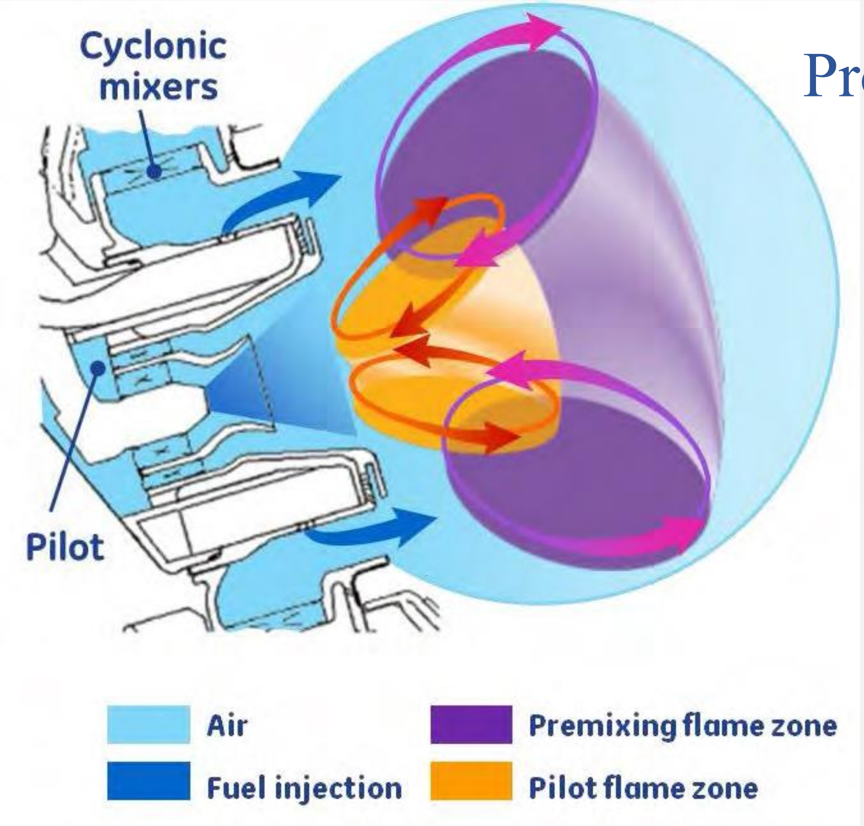
High oil costs + the need to reduce pollution and dependence on foreign suppliers has spurred great interest and activity in developing alternative aviation fuels

NASA Fundamental Aeronautics supported efforts in studying the effects of fuel alternatives in combustion and in engines, including
Alternative-Fuel Effects on Contrails and Cruise Emissions (ACCESS)
Alternative Aviation Fuels Experiment (AAFEX)

NASA ERA supports alternative fuels research: develop and demonstrate a low NOx *Fuel flexible combustor* that provides a 75% reduction in oxides of nitrogen below the current CAEP 6 standard with no increase in particulate matter, while achieving a 50 percent reduction in fuel burned

Task objectives
—using GE TAPS single cup flame tube as a test bed
Ascertain visible luminosity, sooting, fuel spray pattern, liquid fuel penetration, flame zone location of Hydrotreated Renewable Jet (HRJ) fuel compared to JP-8.
Means: 1. high-speed imaging (grey scale) for structure, flame length, luminosity
2. Planar laser scatter of fuel drops
3. Fuel and OH planar laser-induced fluorescence (PLIF)

GE Twin Annular Premixing Swirler (TAPS) injector concept for low NOx emissions



Provides independent control of:

- Center pilot for low power operability, low CO, HC emissions
- Cyclone/main for high power operation, low NOx emissions

References:
Foust, Thomsen, Stickles, Cooper, Dodds—AIAA 2012-0936
Mongia—AIAA 2003-2657

Comparing fuel physical properties

	Fuel	JP-8	HRJ
components	Sulfur (ppm)	1148	<3
	Olefins (%vol)	**0.9**	**0.4**
	Aromatics (%vol)	**18.6**	**0.4**
	Naphthalenes (%vol)	**1.6**	**0**
Distillation characteristics	Initial boiling point, °	158	165
	10%	176	179
	90%	248	243
	End Point	273	231
	Flash Point °C	46	55
	API Gravity	41.9	54
	Specific Gravity	0.816	0.758
	Freezing Point °C	-50	-62
	Viscosity	4.7	5.3
	Cetane Index	**41**	**67**
	H Content (%mass)	13.6	15.3
	Heat combustion (MJ/kg)	43.3	44.5
	Fuel H/C ratio	**1.88**	**2.12**

Similar reactivity

HRJ:

Fewer aromatics:

Less luminous

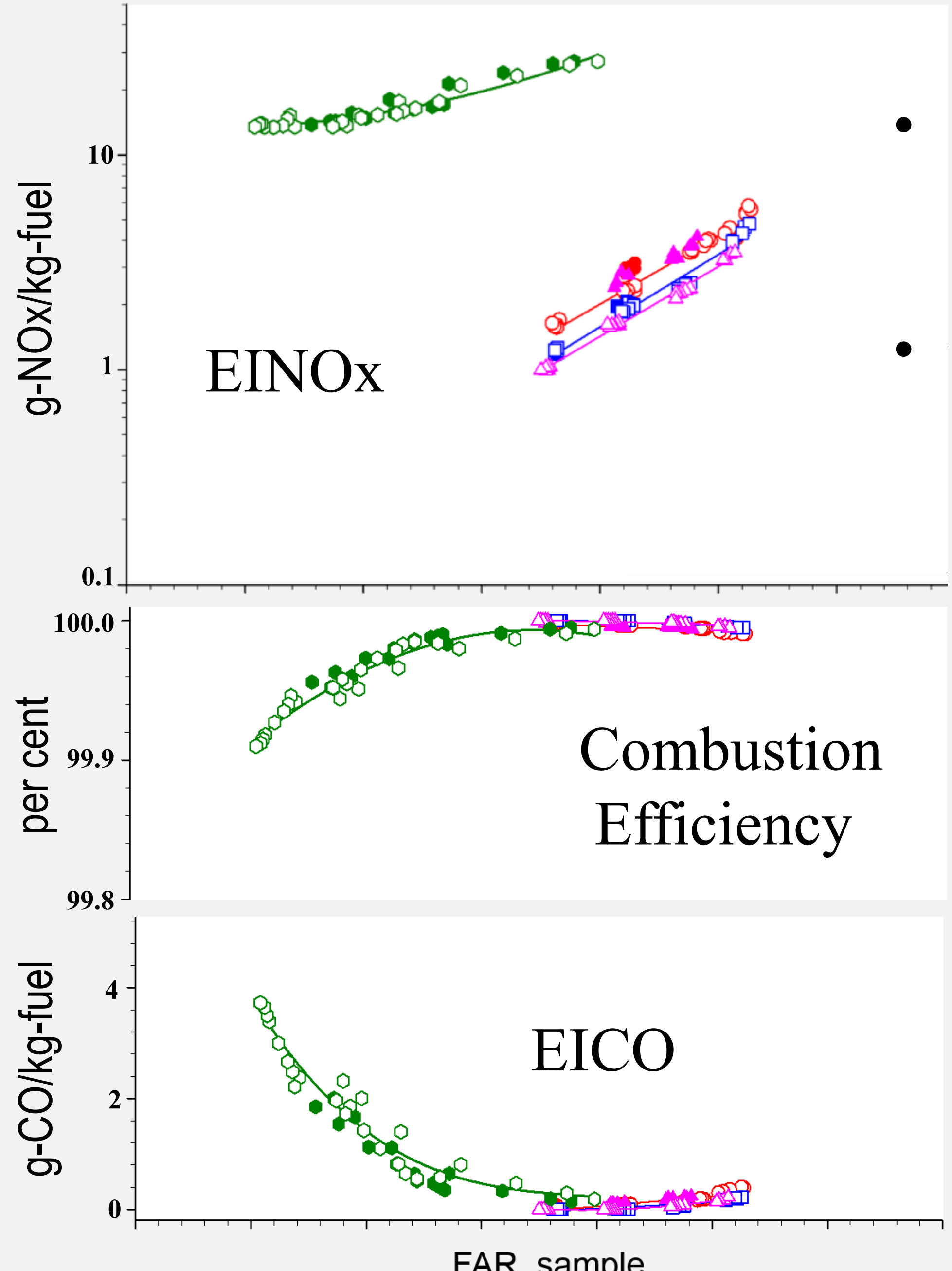
Higher cetane index:

Shorter ignition delay

Expectation: more soot production from JP-8—greater luminosity

HRJ constituents—shorter ignition delay time

TAPS Gaseous Emissions Results—Fuel type comparison

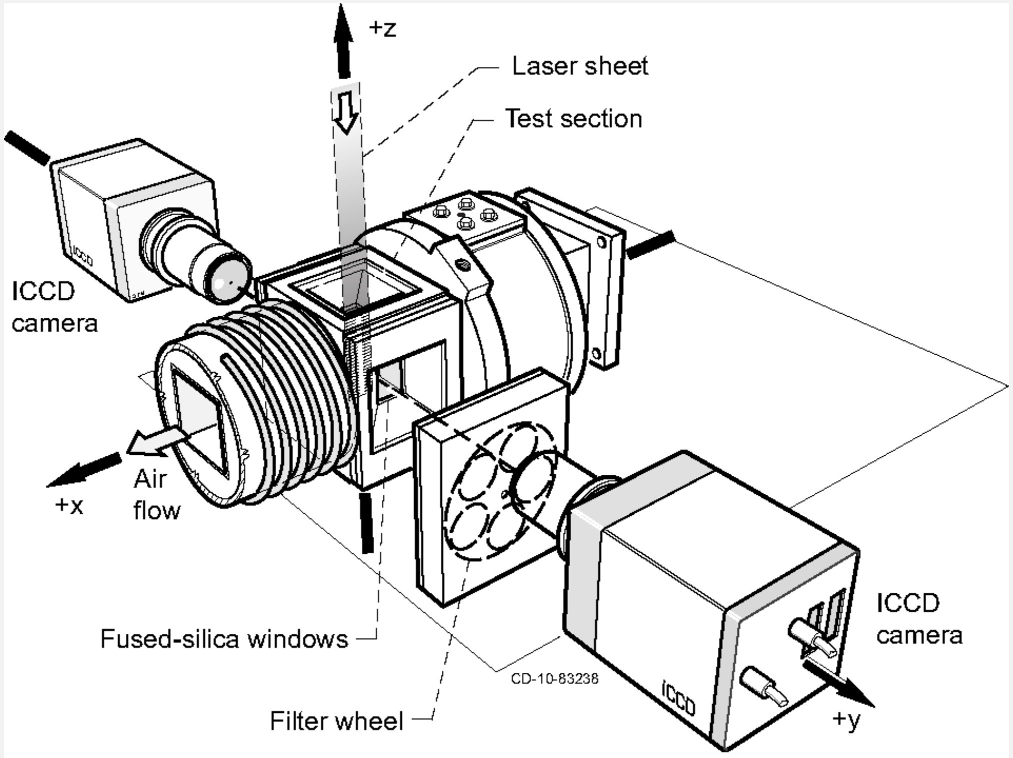


- No discernable difference between fuel types in combustion efficiency or emissions.
- This result is similar to other fuel comparison tests using different fuel-air mixers.

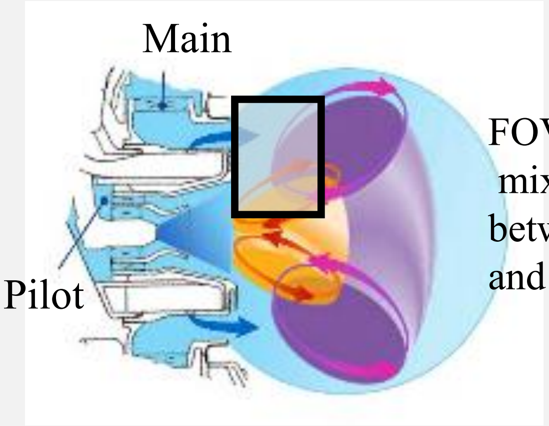
Legend: P_3, T_3, pilot/main split, fuel

- ● 250 psia, 1000°F, 10/90 split, HRJ
- ○ 250 psia, 1000°F, 10/90 split, JP8
- ■ 250 psia, 1000°F, 10/90 split, HRJ
- □ 250 psia, 1000°F, 10/90 split, JP8
- ▲ 170 psia, 1000°F, 10/90 split, HRJ
- △ 170 psia, 1000°F, 10/90 split, JP8
- ⬢ 208 psia, 1000°F, 100/0 split, HRJ
- ⬡ 208 psia, 1000°F, 100/0 split, JP8

Optical Diagnostics Setup and Testing



Test Point	P_3 psia	T_3 °F	Fuel Split % Pilot/Main	FAR/FAR_{SLTO}
1	166	650	100/0	0.48
2	200	925	10/90	0.94
3	200	1000	20/80	0.94
4	200	1000	10/90	0.94



Laser: 10-Hz Nd:YAG→ **dye** → **UV**: ~282-nm

- Planar Laser induced fluorescence (PLIF) of OH and Fuel, 100-ns gate
- Planar Laser Scatter (PLS) for Liquid Fuel, 100-ns gate
- Instantaneous imaging of CH* chemiluminescence, 100-ns, 100-µs

  Camera: Princeton Instruments PIMAX, 1k x 1k pixel

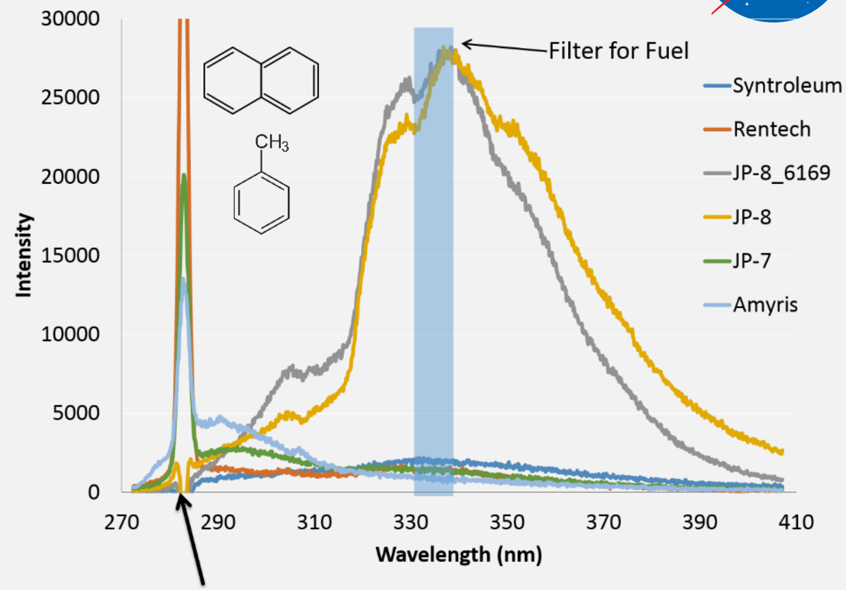
- High Speed Flame Imaging via Chemiluminescence of CH*, C_2*

  Camera: Photron Fastcam SA1, 1k x1k px, 10000 frames/s

Optical diagnostics expectations based on fuel composition

Fuel	JP-8	HRJ
Sulfur (ppm)	1148	<3
Olefins (%vol)	0.9	0.4
Aromatics (%vol)	18.6	0.4
Naphthalenes (%vol)	1.6	0

- more aromatic content in JP-8: higher soot production
  → greater luminosity

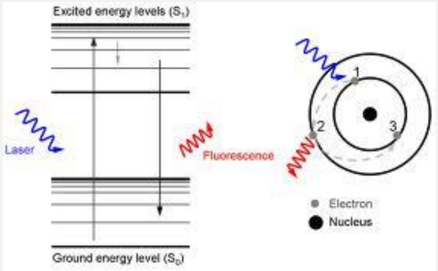


Laser Wavelength Used for OH, fuel excitation)

Light is either absorbed, scattered, or transmitted through matter.

$$I_{trans} = I_{incident} - I_{absorbed} - I_{scattered}$$

PLIF requires **absorption** by fuel constituents before the excited molecules can emit light

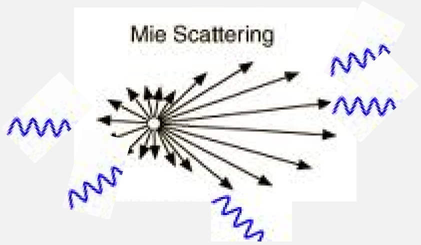


Naphthalenes and Methylbenzenes used for Fuel PLIF, so

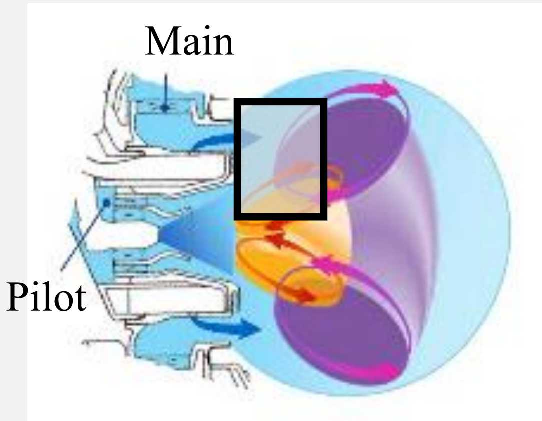
- fuel PLIF signal greatly reduced for HRJ
- OH PLIF signal may be increased

but More laser energy available for scattering from liquid

- PLS signal increased



Flame Chemiluminescence: CH*



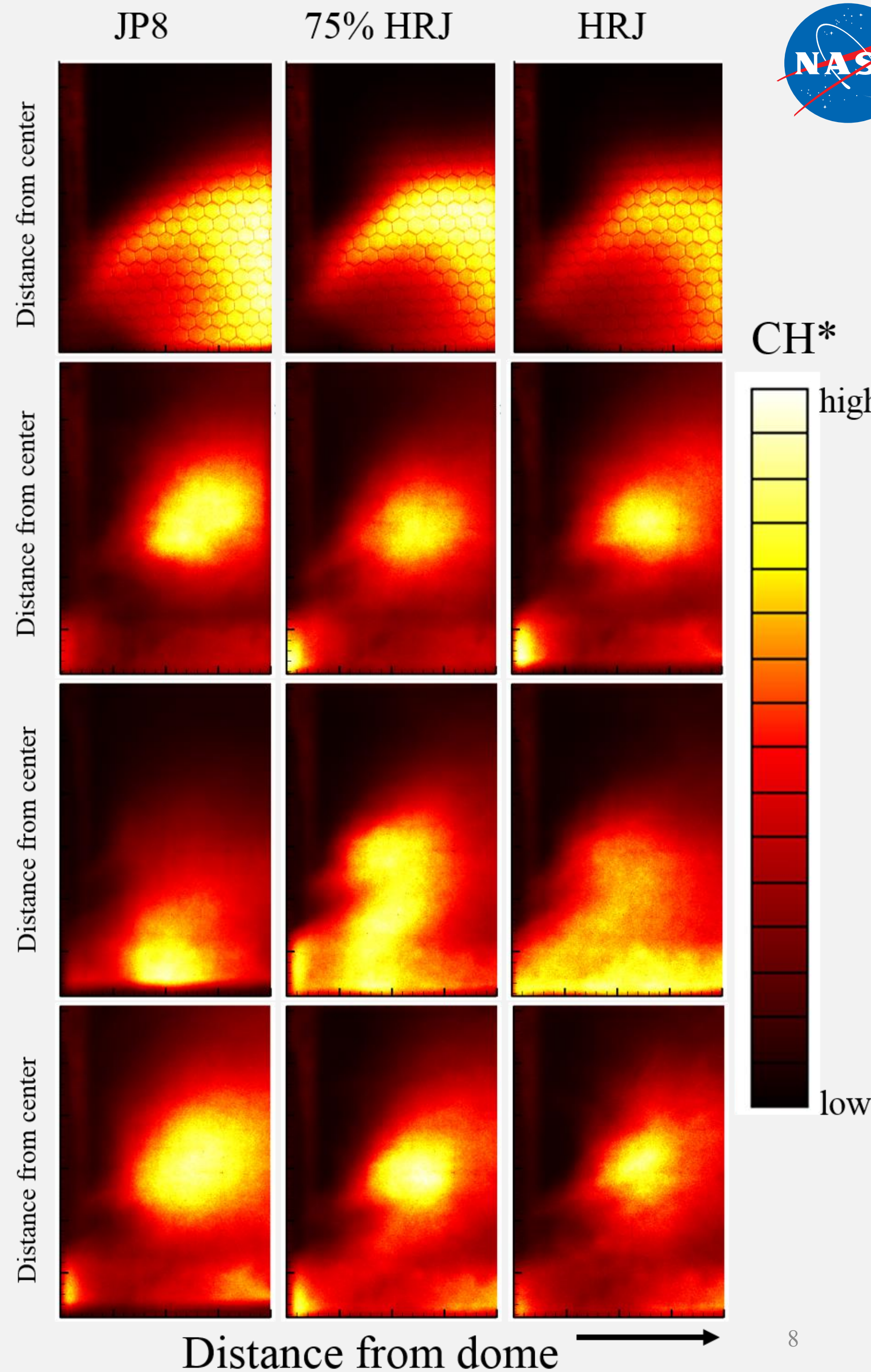
% pilot flow affects flame structure

Point 1
100/0
650°F

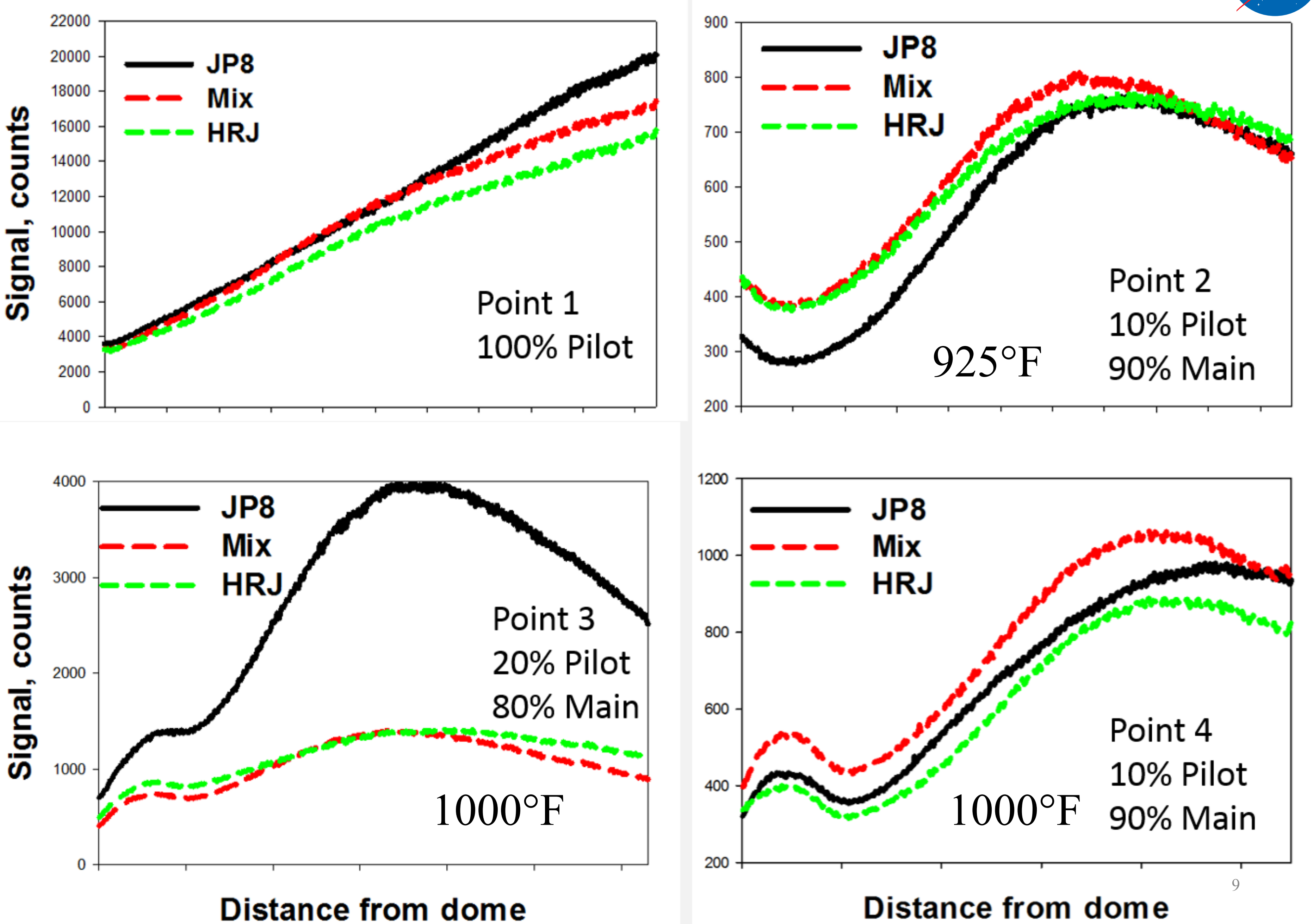
Point 2
10/90
925°F

Point 3
20/80
1000°F

Point 4
10/90
1000°F



CH* results—total signal per image column with downstream location



High speed flame imaging—C_2, CH* pilot only*

Frame rate: 10000/sec, 100-μs exposure

Image Resolution 768 x 768 pixels

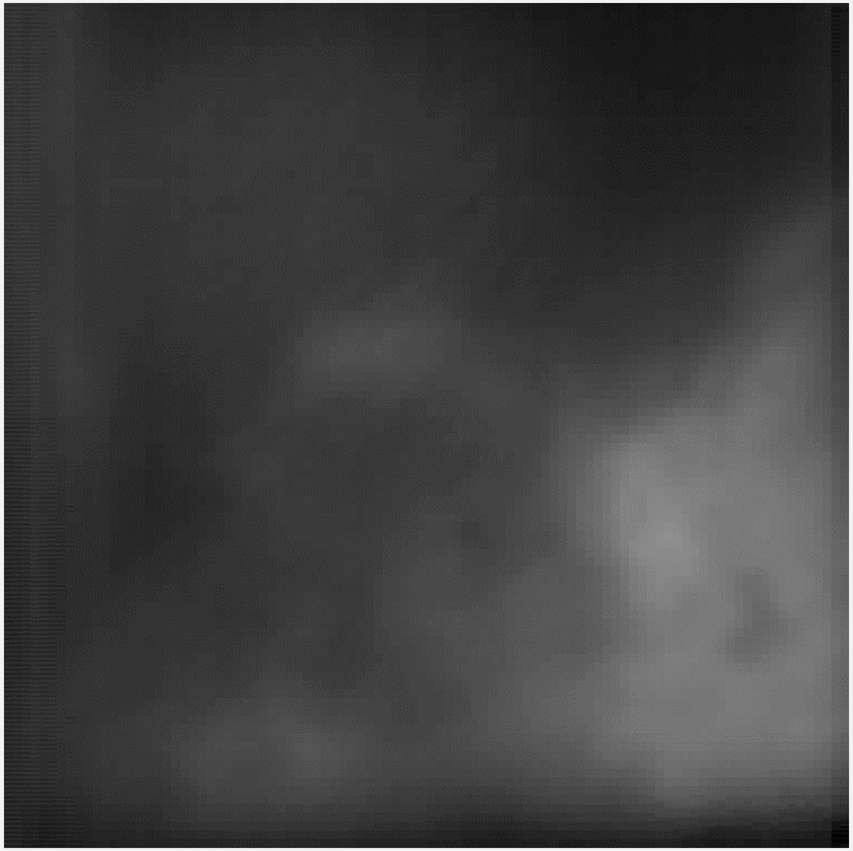
Flow direction left to right

JP-8

Distance from center

Distance from dome

HRJ



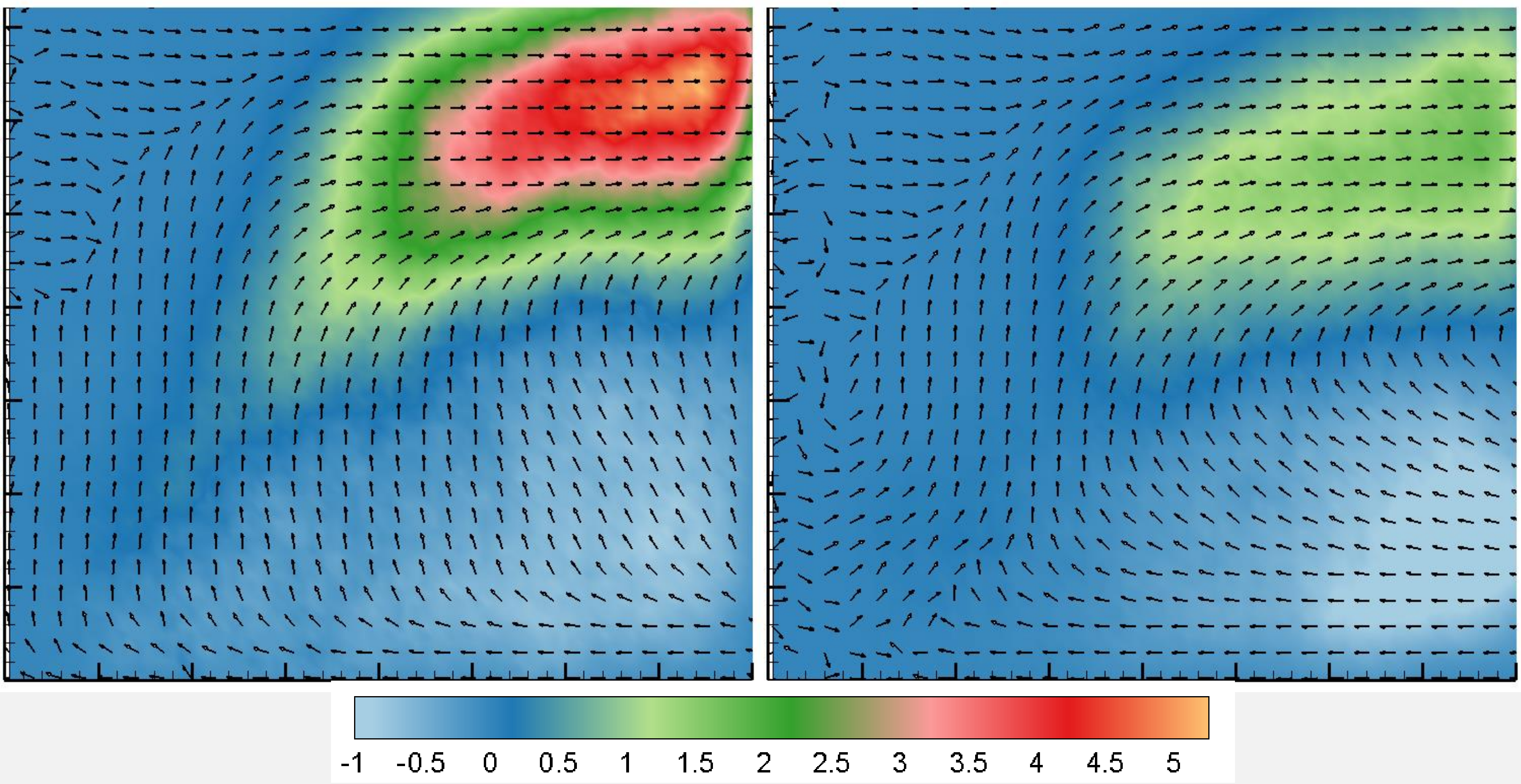
Distance from dome

- JP-8 flame more luminous than HRJ flame
- Central recirculation zone can be seen

High speed video results—100% pilot, test point 1

- high speed camera frames (9701 images) processed as time-resolved PIV
- flow: left to right

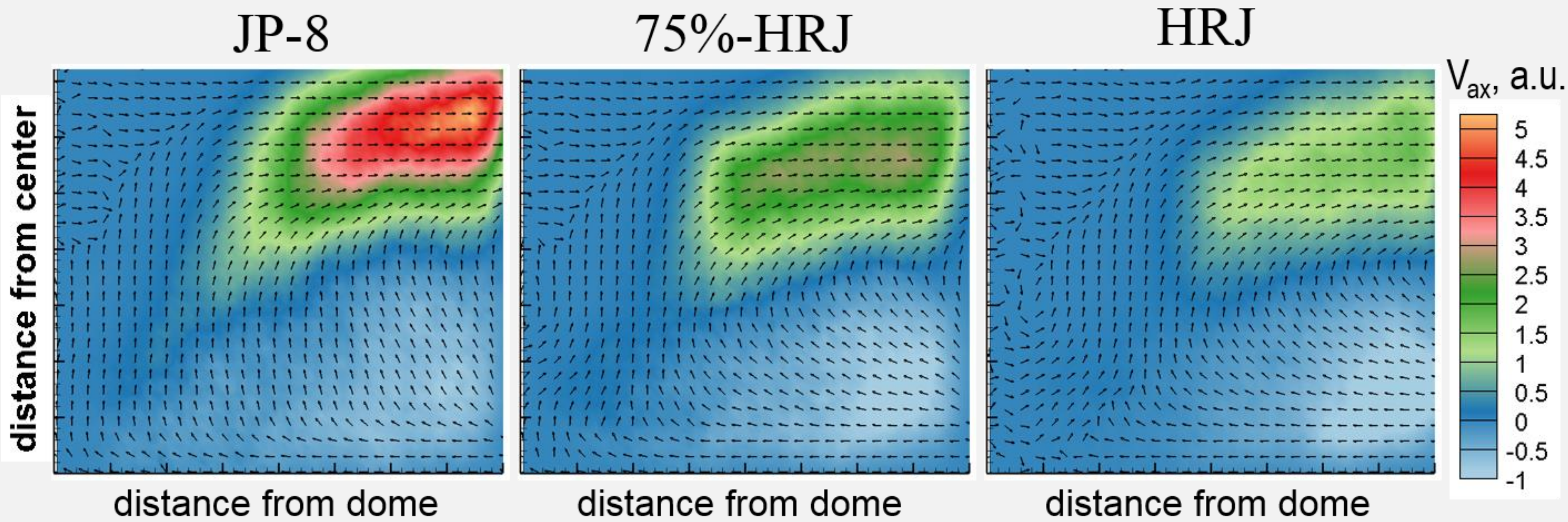
JP-8 HRJ



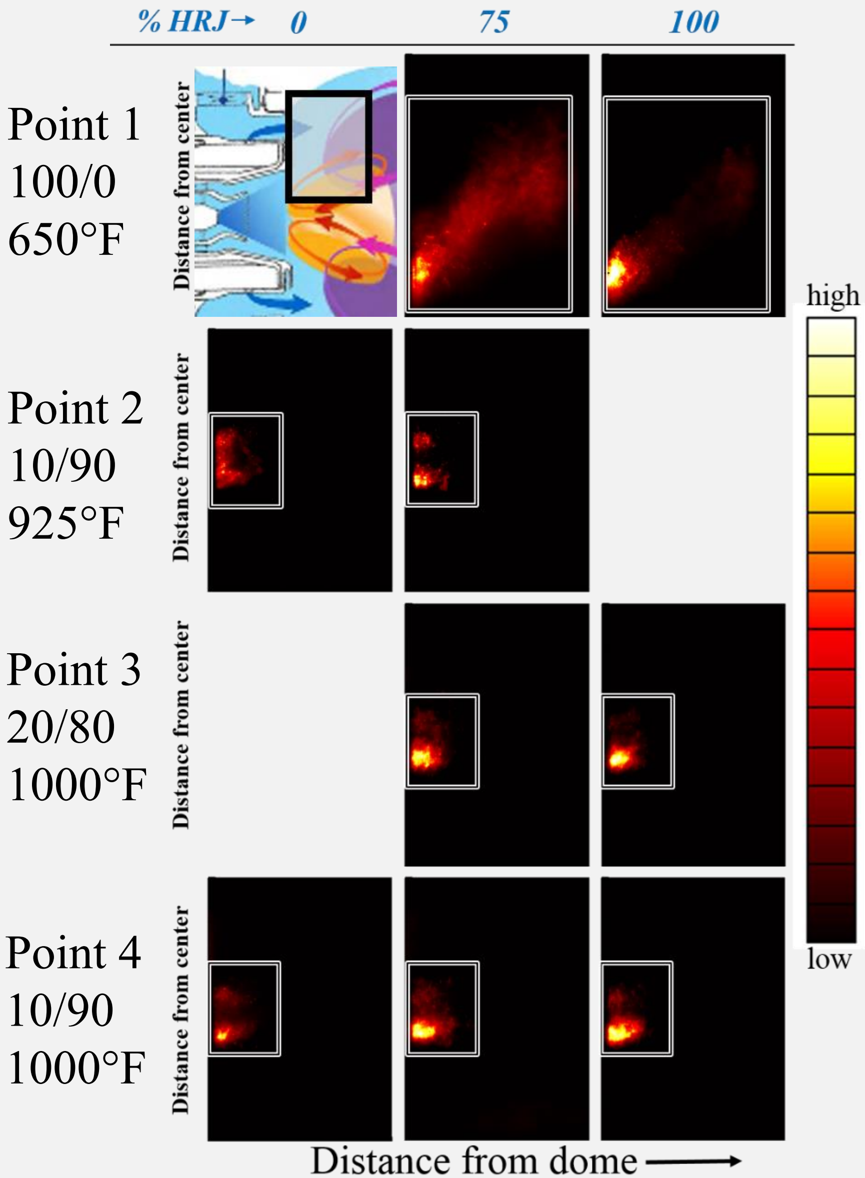
Vectors give bulk average direction of motion—correspond visually
Contour shows the relative degree of change, on average

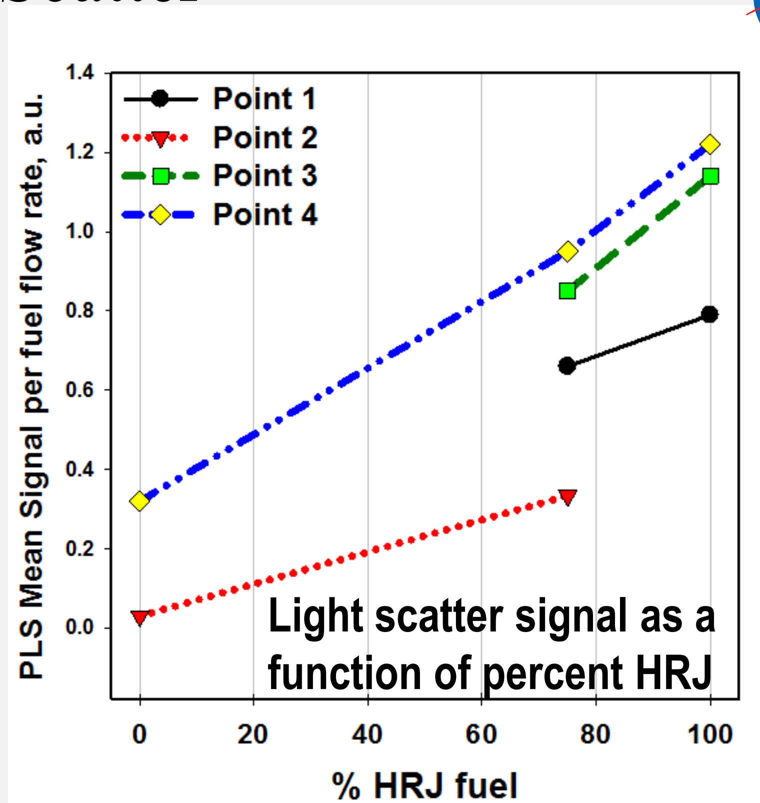
High speed video results—100% pilot, test point 1

Fuel Mixture shows results intermediate to the neat fuels

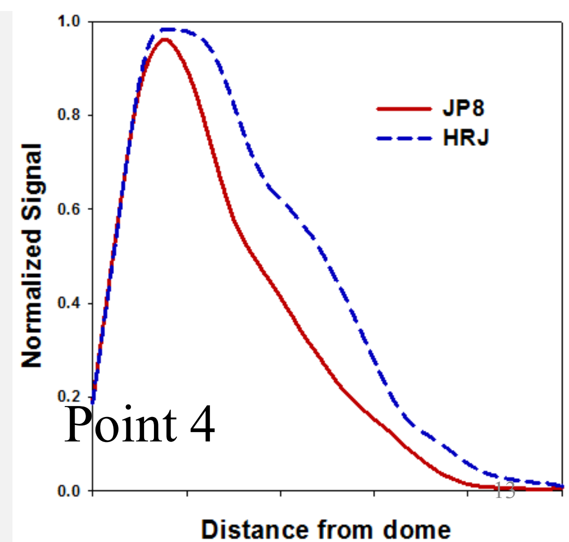


Liquid fuel results, Planar Laser Scatter



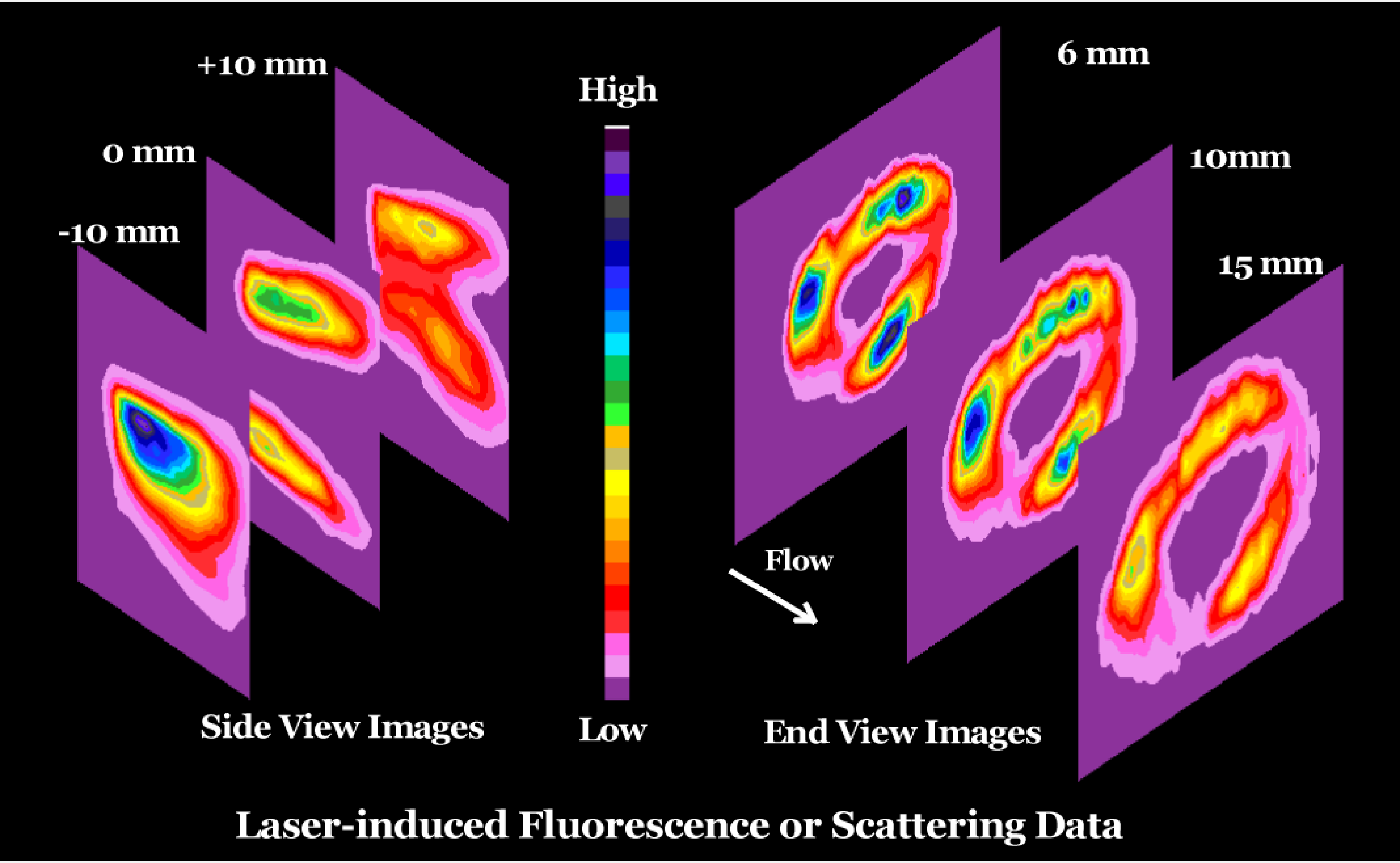


Liquid signal decay →



Above: average of 100 single shot images

Next: OH, fuel PLIF Results and Field of View Perspective:



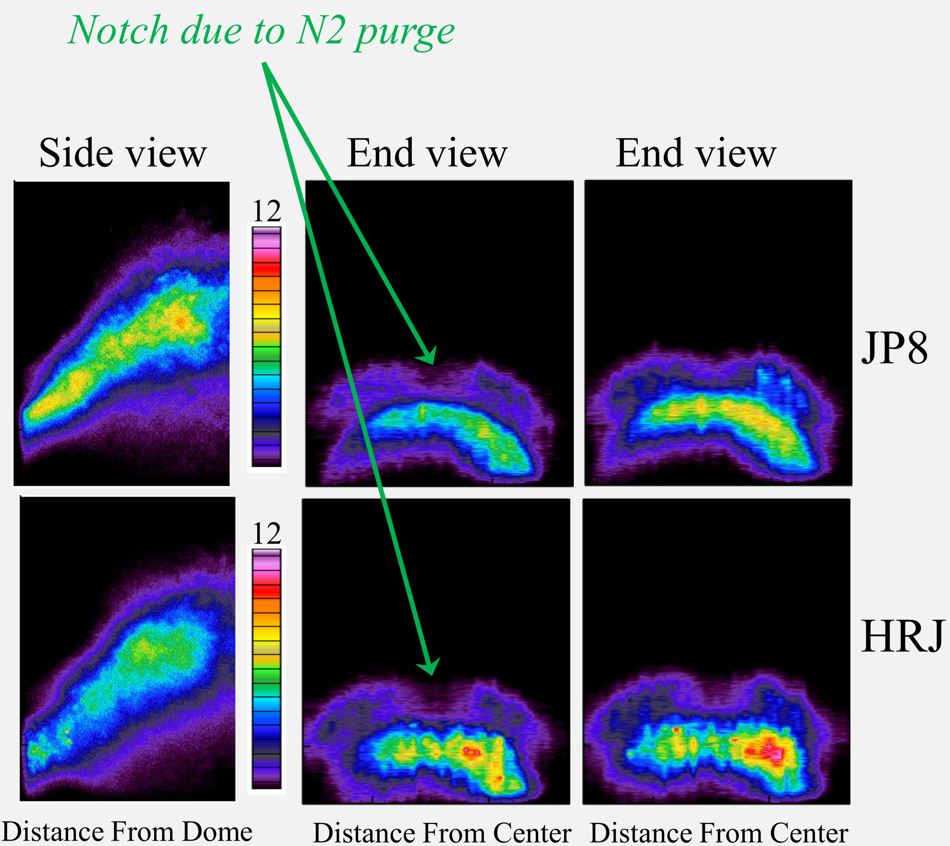
Left: laser sheet oriented with flow, traversed across flow, side view images

Right: resulting traverse block sliced at fixed axial positions to produce End View images

Comparing HRJ and JP8 via Planar Laser Induced Fluorescence

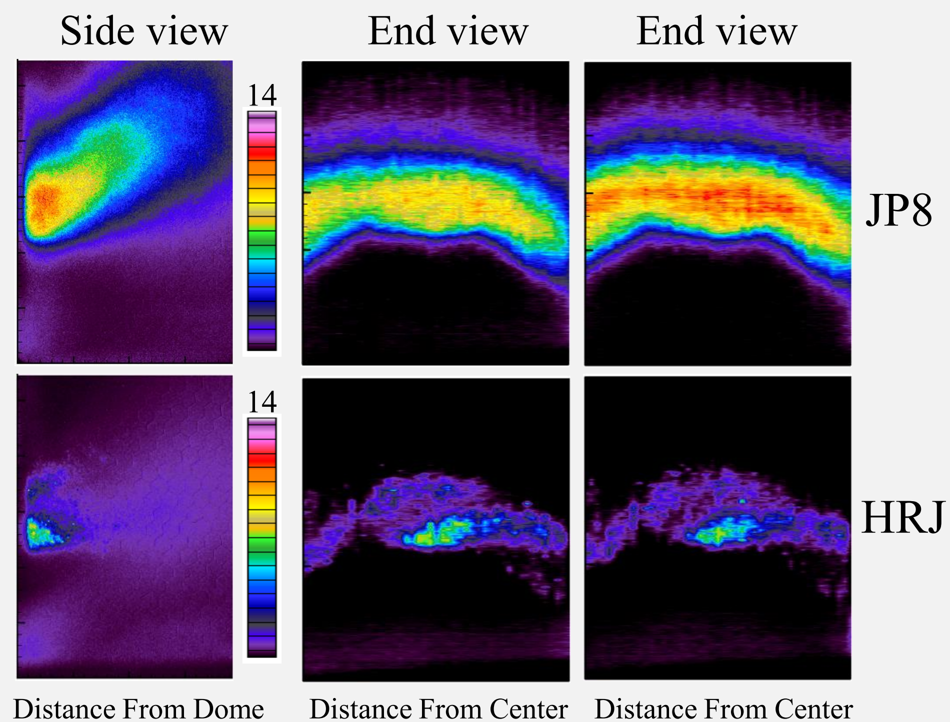
Fuel PLIF

Point 1, pilot only



For pilot only, JP8, HRJ have similar spray pattern

Point 2, 10/90 split, T_{in} = 925°F



JP8: uniform distribution within annulus

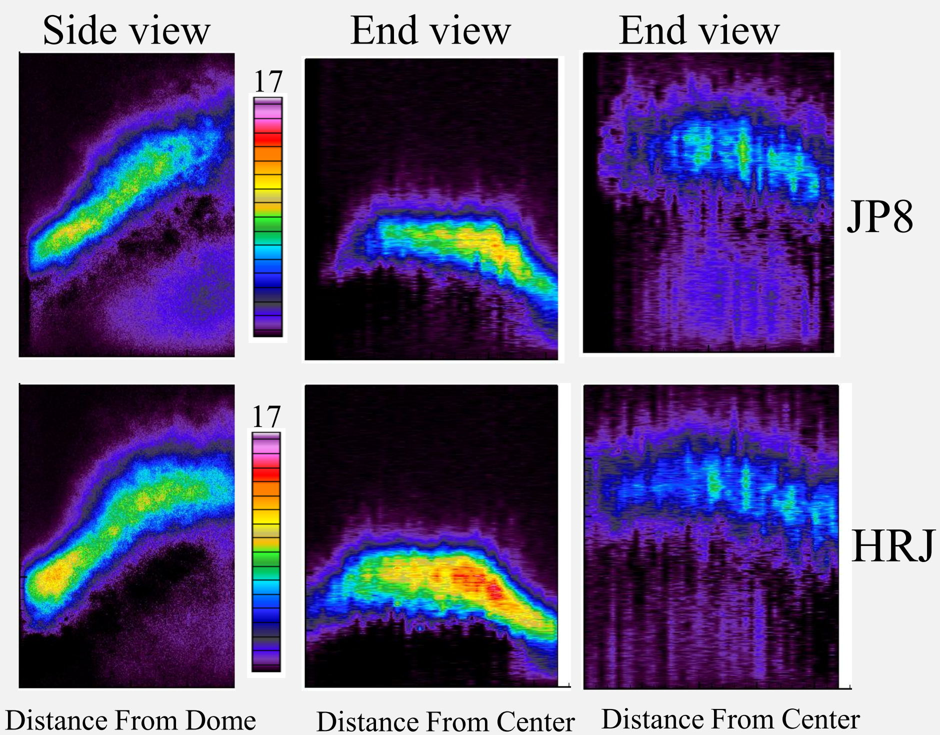
HRJ: Most fuel observed near wetted annular walls

Possibly only HRJ liquid seen because greater number density than in gas phase

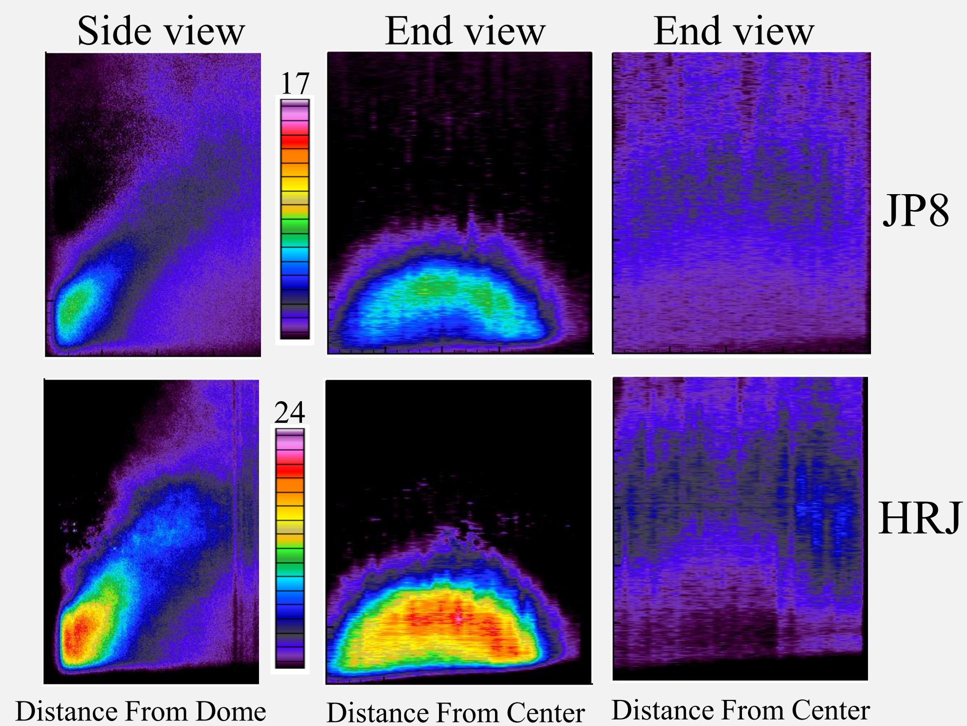
Comparing HRJ and JP8 via Planar Laser Induced Fluorescence

OH PLIF

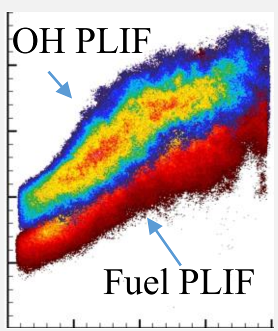
Point 1, pilot only



Point 2, 10/90 split, T_{in} = 925°F

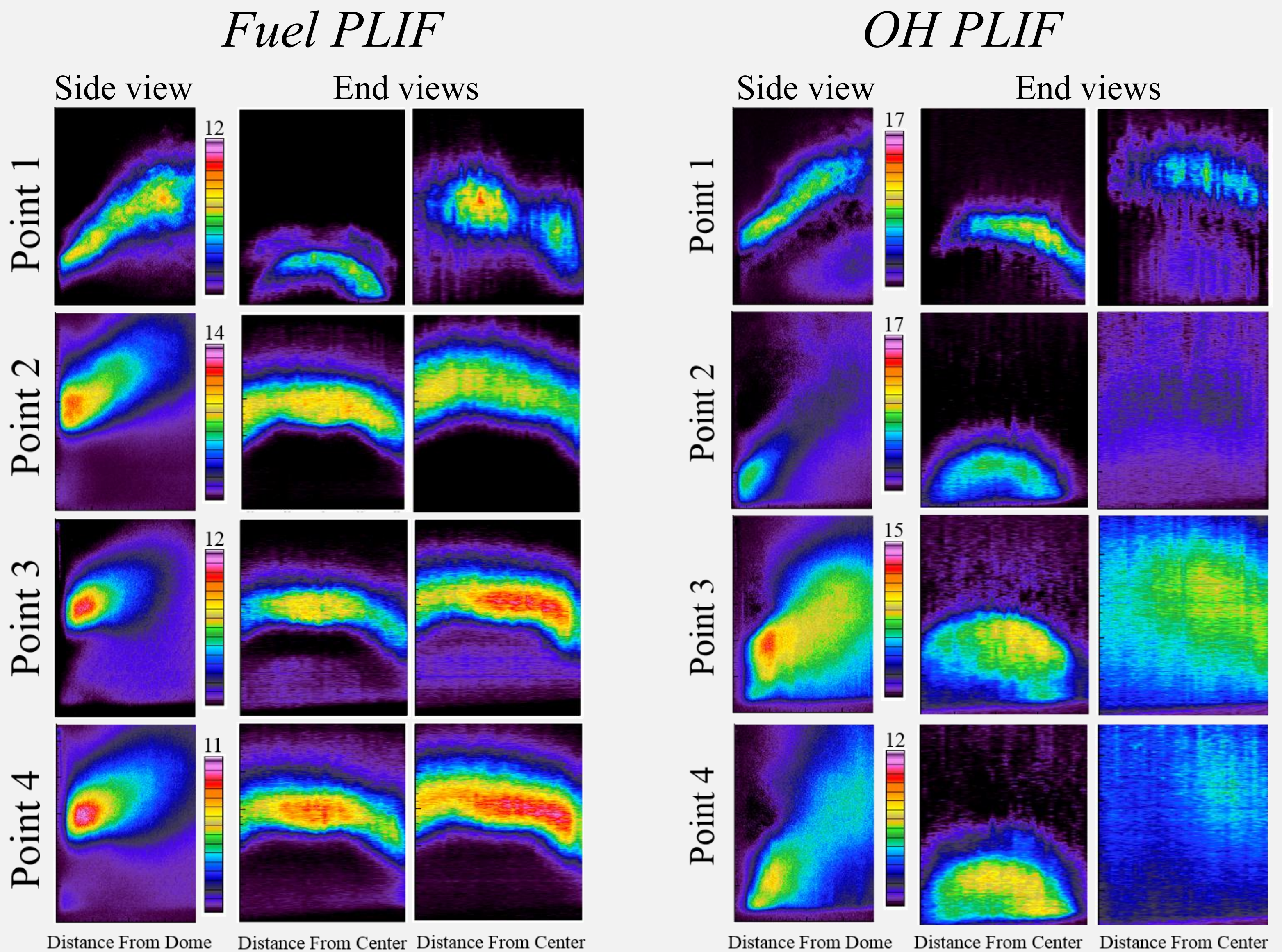


OH PLIF signal not as strong in CRZ for HRJ, but stronger on air side of spray cone:



- Similar patterns for JP8, HRJ
- HRJ signal stronger than for JP8 likely because little absorption by fuel

JP8: Compare four test points using PLIF



Summary

- A single-cup GE TAPS injector used to compare JP-8 and tallow HRJ, using sample gas analysis, flame chemiluminescence, PLS, OH and fuel PLIF
- Consistent with other flame tube combustor and engine tests, little or no difference in gaseous emissions of NOx, CO, UHC
- Flame luminescence shows flame structure changes most affected by pilot flow. JP-8 flame ~4x brighter than HRJ flame for 20/80 split. Other splits have comparable luminoscity
- When flow is split between pilot and main, we see liquid from main circuit but not from the pilot. Main circuit fuel does not completely vaporize before exiting the dome.

Summary, cont

Fuel PLIF:

- For HRJ, more fuel observed along the wetted walls of annulus, whereas with JP8, uniformly distributed
- Likely for HRJ,PLIF results primarily from the liquid phase, where the number density of aromatics is greater than in the gas phase
- Future Fuel PLIF with low aromatic fuel will need to use shorter wavelengths (~266 nm) for better signal

OH PLIF:

- Similar patterns are observed for both fuels in the flow split case. Under pilot only operation, little OH is observed in the central recirculation zone for the HRJ

Acknowledgment

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- Dr. Changlie Wey was the lead research engineer and provided the gas analysis results.

Questions?